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Influence of Pretreatment Combinations on Drying Time and Quality of Melon Chips Produced by Vacuum-Assisted Two-Way Infrared Drying

Running title: Influence of Pretreatment Combinations on Melon Chips

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SUMMARY

Research background. Infrared technology, which has become widespread in recent years due to its rapid drying effect, also causes some negative changes in the products. To eliminate the negative effects that occur during the drying process in dried products, different pretreatments such as dipping, blanching, freezing, and ultrasonic treatment are applied.

Experimental approach. This study aimed to determine the effect of different pretreatments (citric acid, ethanol, ultrasound, blanching, and freezing) and their combinations on drying time and quality characteristics of melon chips produced by a novel vacuum-assisted two-way infrared dryer.

Results and conclusions. The samples produced with the combination of citric acid/ethanol/ultrasound/freezing had the highest rehydration ratio (6.07 %), shortest drying time (72.5 min), lowest specific energy requirement (2.59 kWh/kg), and shrinkage ratio (85.7 %). The best result

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in terms of color values was obtained from the samples treated with the citric acid/ethanol combination. 5-hydroxymethylfurfural (HMF) contents in melon chips produced with pretreatments including ultrasound application were higher (74.92–117.98 mg/kg DM) than other pretreatments. Multiple pretreatment applications caused a decrease in total phenolic content and antioxidant activity. The highest total phenolic content (2565.34 mg GAE/kg DM) and DPPH value (7.47 mmol TE/g DM) were found in samples immersed in citric acid. The most liked melon chips were the samples in which citric acid/blanching combination was used.

Novelty and scientific contribution. Infrared drying is emerging as an increasingly widespread drying technology. The primary innovation of this study is the investigation of how two-way vacuum-assisted infrared technology can mitigate or eliminate the disadvantages of infrared drying by leveraging the benefits provided by various pretreatment processes used in chips production. As a result, it was found that a combination of citric acid and blanching pretreatments can be used to reduce the negative effects of the vacuum-assisted infrared drying, which provides rapid drying, on the product and to produce more flavorful and appealing melon chips.

Keywords melon chips; pretreatments; quality properties; specific energy; vacuum assisted infrared drying

INTRODUCTION

Melon fruits with high economic value are widely cultivated in warm and temperate climates. Due to its high nutritional value, pleasant taste, and aroma, it is enjoyed and consumed worldwide. Tokuşoğlu [*1*] reported that potassium, magnesium, calcium, ascorbic acid, β-carotene, total phenolic content, and antioxidant capacity of the Kırkağaç melon variety was 23651–35823 µg/g, 653–1593 µg/g, 280–1600 µg/g, 36.7 mg/100g, 2020 µg/100 g, 233.42 mg GAE/kg, and 12.08 mg/mL, respectively. Although melons are generally consumed fresh, one of the most common ways of consumption is dried melon. The drying of crops has been a common practice to prolong their shelf-life.

However, drying causes some negative changes in the texture and appearance of the product (shrinkage, cracking, hardening) and significant loss in nutrients, flavor, and color compounds [*2*]. In recent years, innovative drying techniques such as fluid bed, lyophilisation, microwave, vacuum, infrared, and spray dryers have been developed to reduce adverse changes in products, drying time, and energy consumption [*3*]. Compared to other innovative technologies, infrared technology stands out due to its fast-processing time, low cost, and high energy efficiency. Therefore, it has become a frequently used technology in food drying processes in recent years [*4*]. Melon slices were dried by the convective method and infrared assisted convective method. While the convective drying took 50 h, the infrared-assisted convective drying was completed in 18 h [*5*]. Infrared energy from the heat source is irradiated onto the heated surface. The energy density in the area penetrated by the rays is very high and this energy is absorbed directly by the inner layers of the material. The infrared waves do not require a medium to propagate, they can also propagate in a vacuum. This is one of the most important advantages of infrared radiation. The use of infrared radiation in combination with a vacuum is particularly successful in the processing of oxygen-sensitive products and prevents energy losses [*6*]. Despite its many superior properties, infrared drying has some disadvantages, such as crust formation, browning on the surface, and partial burning. Drying at especially high infrared power causes crust formation due to rapid heat transfer. Topuz *et al*. [*7*] and Uğurlu *et al.* [*8*] noted that the rehydration rate of the dried pear and apple, respectively, decreased due to crust formation at high infrared power. Topuz *et al.* [*9*] reported that the *a** values and HMF contents of pear slices dried by the conventional dryer at 40, 55 and 70 °C was lower than those of sample dried by vacuum combined infrared dryer at 100, 200 and 300 W (40, 55 and 70 °C).

Some pretreatments before drying are applied for various purposes such as flavor formation, rehydration capacity, shrinkage control, appearance and color improvement, and preservation of bioactive components in dried products. Different processes such as dipping, blanching, freezing, and ultrasound were used as pretreatment [*10*]. da Cunha *et al.* [*11*] evaluated the effects of ethanol, ultrasound, vacuum, and ultrasound-vacuum combination pretreatments on convective dried melon. The pretreated samples dried faster than the control samples, and the losses in total phenolic content and ascorbic acid were less. Tepe and Kadakal [*12*] reported that the shrinkage rate in melon samples dried convectively at 70 °C without pretreatment was 82.63 %, whereas the shrinkage rates of samples pretreated by blanching, 100 % ethanol, 0.5 % citric acid, and ultrasound ranged from 80.23 % to 80.48 %. The effect of pretreatments on the quality characteristics of foods dried by infrared radiation are limited studied. In fact, we did not find any studies on multi pretreatment applications in vacuum-assisted two-way infrared drying. In this study, the effects of multi pretreatment combinations on drying time and product quality of melon chips dried by vacuum-assisted two-way infrared radiation were investigated.

MATERIALS AND METHODS

Sample preparation

Kırkağaç melon variety was used in the study, which was obtained from a local market in Van province of Türkiye. The melons were quickly transferred to the laboratory and kept in a refrigerator at 4 °C until they were used in the studies. After the melons were washed and cleaned, the skin and seeds were removed. The fruit flesh was cut into 4 cm width, 5 cm length, and 2–3 mm thick slices with a stainless-steel manual slicer. For all dipping processes in pretreatments, 150 g samples and 600 mL solvent were added in the glass beaker (1000 mL). The ratio of fruit slice to dipping solution (1:4, *m*/*V*) was determined by preliminary experiments. The following pretreatments were applied to the sliced melons.

Citric acid pretreatment (CA): melon slices were immersed in 0.5 % citric acid (food grade, Balmumcu, Türkiye) solution prepared in water for 7 min. These samples were considered the control group.

Citric acid/ethanol pretreatment (CA+ET): melon slices were immersed in 0.5 % citric acid solution prepared in ethanol (99.8 %) (3086612, Carlo Erba, France) for 7 min.

Citric acid/ultrasound pretreatment (CA+US): melon slices were immersed in citric acid (0.5 %) solution prepared in water for 20 min. Ultrasound was applied at (30±2) °C and 100 % amplitude during the immersion. Temperature control was maintained with ice packs throughout all ultrasound procedures. The ultrasound-assisted immersion was performed using a Bandelin Sonoplus HD 3200 ultrasonic homogenizer (Berlin, Germany) equipped with Bandelin UW 3200 ultrasonic transducer (200 W max. power, 20 kHz) and VS70T titanium probe (diameter 13 mm).

Citric acid/ethanol/ultrasound pretreatment (CA+ET+US): melon slices were immersed in 0.5 % citric acid solution prepared in ethanol (99.8 %) for 20 min. Ultrasound was applied at 100 % amplitude during immersion.

Citric acid/blanching pretreatment (CA+BL): melon slices were immersed in 0.5 % citric acid solution prepared in water at 80 °C for 7 min.

Citric acid/ethanol/ultrasound/blanching pretreatment (CA+ET+US+BL): melon slices were immersed in 0.5 % citric acid solution prepared in ethanol (99.8 %) at 78 °C for 20 min. Ultrasound was applied at 100 % amplitude during immersion.

Citric acid/freezing pretreatment (CA+FT): melon slices were frozen in a deep freezer (D405DD, Şenocak, Türkiye) at −24 °C for 16 h. Frozen melon slices were removed from the freezer and then immediately thawed by immersion in 0.5 % citric acid solution prepared in water at room temperature for 7 min.

Citric acid/ethanol/utrasound/freezing pretreatment (CA+ET+US+FT): melon slices were frozen in a deep freezer at −24 °C for 16 h. Frozen melon slices were removed from the freezer and then thawed by immersion in 0.5 % citric acid solution prepared in ethanol (99.8 %) for 20 min at room temperature. Ultrasound was applied at 100 % amplitude during immersion.

After pretreatment, excess water on the melon slices was removed using filter paper. This was followed by the drying process. Each pretreatment application was performed in five replicates.

Drying procedure

A vacuum-assisted two-way infrared oven (Uniterm, Ankara) was used for drying. The oven consisted of four 250 W infrared lamps, two at the ceiling and two at the floor. The temperature inside the oven was monitored by a thermocouple. The thermocouple probe was placed between the samples on the tray in a position where it would be exposed to the light. The vacuum atmosphere inside the dryer was provided by a vacuum pump (DOA-P730-BN, Pall Life Sciences, USA). Melon slices were dried under 200 W infrared power (55 °C) and 450 mmHg vacuum pressure until the final moisture level (<9 %). A large perforated stainless-steel tray was used to receive more light from the infrared lamps placed on the floor of the oven. The distance between the samples and the lamps was 12 cm from both top and bottom. Approximately 150 g of pretreated fresh melon slices were placed on the tray for drying.

Specific energy consumption

In the study, the total energy consumption required for the pretreatment and drying stages of 1 kg of melon was determined according to the following equation:

$$E_s = \frac{E_{\mathrm{t}}}{m_0} \qquad /1/$$

where E_{s} is the total amount of specific energy (kWh/kg), E_{t} is the total amount of electrical energy consumed during the processes, and m_0 is the initial sample mass (kg). A power analyzer (CAT II, Intertek, Turkey) was used to measure the total electrical energy consumption [*13*].

Moisture content

Moisture content was determined by drying the samples in measured vessels at 105 °C until constant mass [*14*].

Color

The CIE color values (*L**, *a**, and *b**) of the samples were determined using PCE Instruments (CSM1, UK) colorimeter [*15*].

Rehydration and shrinkage ratio

For rehydration ratio, melon chips were placed in glass jars with fruit:water ratio of 1:50 and rehydrated at 20 °C for 24 h. After rehydration, the chips were filtered by keeping them on a strainer for 30 s and then the excess water on the surface was removed with a paper towel and weighed. Rehydration ratio was calculated according to the following equation [*16*]:

$$\text{Rehydration ratio} = \frac{m(\text{rehydrated sample})}{m(\text{dried sample})} \quad /2/$$

The shrinkage ratio was analysed according to Reyes *et al*. [*17*] with some modifications. Fresh and dried samples (0.5 g) were kept in 5 mL of hexane. The volumes of fresh and dried samples were measured by the liquid displacement method and the shrinkage ratio was calculated according to the following equation:

$$\text{Shrinkage ratio} = \left(\frac{V\text{i}-V\text{f}}{V\text{i}}\right) \cdot 100 \quad /3/$$

where V_i is the initial volume (mL) and V_f is the final volume (mL).

Sugar content

Sugar extraction and analysis was performed according to Míguez Bernárdez *et al.* [*18*]. The extract was filtered through a 0.45 µm PVDF syringe filter and injected into an HPLC system (LC-20 AD, Shimadzu, Japan) connected to a RID 20A refractive index detector. Intersil NH2 (4.6×250 mm ID, 5 µm) (GL Sciences Inc., Tokyo, Japan) column was used for separation at 25 °C. Acetonitrile:water (80:20) as mobile phase was used in isocratic mode with a flow rate of 1.3 mL/min. Sugars on the chromatograms were identified on retention time by comparison with standards. Results were expressed as g/100 g DM. Total sugar is given as the sum of individual sugars.

HMF

HMF extraction and analysis was performed according to Alves *et al*. [*19*]. The extracts were filtered through a 0.45 µm PVDF syringe filter and injected into the HPLC system (LC-20 AD, Shimadzu, Japan) connected to SPD-M20A diode array detector. Waters Symmetry C18 (250×4 mm ID, 5 µm) column was used for separation at 25 °C. As mobile phase, 2 % acetic acid in water (A) and 0.5 % acetic acid water:acetonitrile (1:1) (B) was used with an elution profile of 10 % B at 0 min and 20 % B at 30 min. The flow rate is 1 mL/min. The identification of the HMF peak on the chromatogram was carried out using retention time and spectrum of a commercial standard (2295.2, Carl Roth, Germany).

Total phenolic content

Total phenolic content was performed according to Singleton and Rossi [*20*]. A volume of 0.4 mL sample extract, 2 mL Folin-Ciocalteu reagent (10 % water diluted), and 1.6 mL sodium carbonate (7.5 %) were mixed. The mixture was kept in the dark for 60 min, after which the absorbance was measured at 765 nm. The results were expressed as mg gallic acid equivalent (GAE) per kg DM.

Antioxidant activity (DPPH and ABTS)

DPPH assay was performed according to Pyo *et al*. [*21*]. A volume of 0.1 mL extract was added to 3.9 mL of DPPH solution (0.025 g/L). The mixture was kept in the dark for 60 min, after which the absorbance was measured at 515 nm.

The ABTS assay was carried out according to Re *et al*. [*22*]. Briefly, $ABTS^{+\cdot}$ radical cation was generated by creating a reaction between 7 mM ABTS and 2.45 mM potassium persulfate via incubation for 12–16 h under a dark room temperature condition. The $ABTS^{+\cdot}$ solution was diluted with ethanol to an absorbance of 0.700±0.05 at 734 nm and $ABTS^{+\cdot}$ solution (1980 µL) was mixed with 20 µL of the extract. The mixture was incubated for 6 min at ambient temperature and the absorbance of the mixture was measured at 734 nm. The results DPPH and ABTS were expressed as mmol Trolox equivalent (TE) per g DM.

Sensory evaluation

Sensory analyses were carried out with 13 semi-trained and pre-informed panelists (6 females and 7 males, aged 25 to 40). Samples were randomly coded with 3-digit numbers and presented to the panelists. The dried melon chips were evaluated for appearance, color, odor, hardness, stickiness, taste, sourness, and general acceptance using a 9-point hedonic scale [*23*].

Statistical analysis

Values were given as mean±standard deviation. For analysis of variance (one-way ANOVA) all data were analyzed using IBM SPSS Statistics v. 25.0 [*24*]. Duncan's multiple comparison test was applied to evaluate the differences between means. Correlation and principal component analysis (PCA) were carried out using SAS JMP v. 13.0 [*25*].

RESULT AND DISCUSSION

Processing times and specific energy consumption

The moisture content and processing times of melon chips are given in Table 1. The moisture content of fresh melon (89.44 %) was reduced to 6.62–8.95 % after drying. Tepe [*26*] found that the average moisture content in fresh melon was 89.56 % and approximately 10 % in dried melon. The results are similar to our findings.

In the study, while CA, CA+ET, and CA+BL had the shorter pretreatment times, CA+FT and CA+ET+US+FT samples including freezing process had the longer pretreatment times. Drying times of the samples varied between 70 and 155 min. Compared to the CA sample, the drying time decreased by 12.90–53.22 %. Blanching, ethanol, ultrasound, and freezing applications accelerated the drying process. CA+ET+US+FT and CA+ET+US+BL samples containing multiple combinations particularly had the shortest drying time with 72.5 and 90 min, respectively. Blanching, ultrasound, and freezing increase the drying rate by damaging the cell wall, while ethanol increases the drying rate by dissolving the water in the tissue. CA+ET+US+FT and CA+ET+US+BL pretreatments had both cell wall damage and the dewatering effect of ethanol. Therefore, they were more effective than individual treatments in reducing drying time. Otağ [*27*] found that pretreatments caused differences in the drying rates of potato slices dried by applying different pretreatments. When the samples were dried after immersion in 100 % ethanol solution, the drying rate was higher than that of the control sample.

The total specific energy consumption for pre-treatment and drying processes in melon chips production varied between 2.59 and 4.73 kWh/kg (Fig. 1). All individual pretreatments reduced the total specific energy requirement compared to CA pretreatment as the positive control. The melon chips produced by freezing particularly had lower total specific energy consumption value than ethanol, ultrasound, and blanching. The specific energy requirement for the drying process (2.22–4.73 kWh/kg) is higher than for pretreatment (0.018–0.83 kWh/kg). When compared to individual pre-treatment, the combined pretreatments such as CA+ET+US, CA+ET+US+BL, and CA+ET+US+FT significantly decreased the specific energy requirement by reducing drying time. The energy specific consumed for drying the samples using ethanol was highly reduced. Similar results reported by Kaveh *et al.* [*28*]. Although CA+ET+US+FT samples had a long processing time due to the freezing process, their specific energy requirement (2.59 kWh/kg) due to the shorter drying time was the lowest compared to all pre-treatment applications. Motevali *et al*. [*29*] calculated the specific energy requirements for drying mushrooms using microwave, microwave-vacuum combination, infrared at different air velocities, and hot air-infrared combination as 2.51–6.0, 3.20–9.60, 47.88–93.45, and 15.04–71.10 kWh/kg, respectively. While reported results for microwave and microwave-vacuum drying are compatible with our findings, specific energy values for infrared drying at different air velocities and hot air-infrared combination are higher. This may be due to design differences. Two-way infrared drying combined with vacuum and pretreatment applications is a more suitable design to reduce specific energy requirement than the application of one-way infrared radiation and its combination with air velocity and hot-air drying.

Some physical quality parameters of melon chips

The color values of samples are given in Table 2. *L**, *a**, and *b** values of fresh melon were 59.20, 0.31, and 9.65 respectively. da Cunha *et al.* [*11*] noted that *L**, *a**, and *b** values of cantaloupe variety fresh melon were 69.76, 18.21, and 38.56, respectively. Our results were higher than the findings of da Cunha *et al.* [*11*]. It may be associated with the different ripening levels, varieties, geographical conditions, and agricultural practices. *L**, *a**, and *b** values of the melon chips were 56.71–74.21, 9.7–16.14, and 27.76–39.67, respectively. The drying process generally increased the *L**, *a**, and *b** values compared to fresh melon. da Cunha *et al*. [*11*] reported that after applying different pretreatments, the *L**, *a**, and *b** values of the dried cantaloupe melon ranged from 39 to 60, 17 to 24, and 31 to 40, respectively. The results obtained from dried cantaloupe melon are similar to the values in the study. The differences among the samples produced with different pretreatments were statistically significant for *L**, *a**, and *b** values ($p<0.05$). The CA+US sample had the lowest *L** and the highest *a** value. Especially the samples produced with pretreatments, including ultrasound application, had lower *L** and higher *a** values than the untreated samples. Cell disruption and high temperature that occur during the ultrasound application may have caused a decrease in brightness and a darker color. The CA+ET sample exhibited the highest *L** and lowest *a** values among the melon chips. The ethanol immersion pretreatment in terms of color values showed the most positive results. da Cunha *et al*. [*11*] reported that the *L** value decreased in dried melon samples with ultrasound pre-treatment. While the *a** value decreased in samples produced with ethanol pretreatment, the *L** value was the highest. Rojas and Augusto [*30*] reported that ethanol pretreatment caused the dissolution and removal of pigments while dissolving cell wall compounds. As a result, *a** value decreased and brightness increased.

The rehydration and shrinkage ratios of the dried samples in the vacuum-assisted two-way infrared dryer after different pretreatments were 3.57–6.07 and 85.7–94.3 %, respectively (Table 2). Tepe [*26*] reported that rehydration and shrinkage rates of cantaloupe melon dried by a convective dryer after different pretreatments ranged from 5.34 to 5.85 and 80.05 to 80.63 %, respectively. While the values reported for rehydration were compatible with our results, the shrinkage values were slightly lower than our results. This may be due to the difference in melon varieties and drying methods used in the study. The effect of the pretreatment combinations on the rehydration ratios of samples was significant ($p<0.05$). The highest rehydration ratio was observed in the CA+ET+US+FT sample, while the lowest was found in the CA sample. In the CA sample, there are no treatments affecting the cell wall. Ethanol, ultrasound, and freezing pretreatments that affect the cell wall caused an increase in the rehydration ratio. Blanching was expected to have a similar effect as it is a heat treatment. However, this effect is not fully observed in the CA+BL process. It may be due to the insufficient blanching time (7 min) used in the CA+BL pretreatment. Carvalho *et al*. [*31*] reported that ethanol pre-treatment and Serna-Cock *et al*. [*32*] reported that freeze drying increased the rehydration capacity of the products.

The pretreatment combinations applied to the samples caused significant changes in the shrinkage rates of the samples ($p<0.05$). The highest shrinkage ratio was observed in the CA+ET sample, while the lowest was found in the CA+ET+US+FT sample. The shrinkage ratio of multiple pre-treatment combinations such as CA+ET+US+BL and CA+ET+US+FT is lower than that of their single-process counterparts. This sample has the highest drying rate, and the increase in drying rate may have reduced the shrinkage ratio. Aral and Beşe [*33*] reported that as the drying rate increases, a mechanical stabilization that limits shrinkage occurs on the surface of the food and this reduces the shrinkage ratio.

Sugar and HMF contents of melon chips

Sugar content is an important quality indicator in melons and their products [*34*]. The fructose, glucose, sucrose, and total sugar content of fresh melon were found as 20.64, 22.44, 33.35, and 76.43 g/100 g DM, respectively, and sucrose was the major sugar (Table 3). Lignou *et al*. [*35*] reported that fructose, glucose, and sucrose in four different melon varieties varied from 20.8 to 21.9, 15.7 to 21.5 and 25 to 46 g/100 g DM, respectively. The reported values are compatible with the values in our study. The sugar content of dried melon chips was lower than that of the fresh sample. The highest fructose, glucose, and total sugar contents in dry samples were found in CA and CA+FT samples. The results show that ethanol, ultrasound, and blanching, except for CA and freezing, lead to significant sugar loss. The differences between the pretreatments were statistically significant for fructose, sucrose, and total sugar values ($p<0.05$). The highest losses in total sugar content were observed in the CA+BL process including the blanching process. When comparing CA+BL and CA+ET+US+BL processes, the higher losses in CA+BL may be due to the difference in the solubility of sugars in water and ethanol. Tang *et al*. [*36*] reported that traditional blanching pre-treatment causes significant losses in sugar content, especially when the temperature of the water used for blanching is chosen to cause as little damage as possible to the texture and content of the product.

HMF is an indicator used to determine excessive heat treatment in thermal processes. The HMF contents of chips changed between 41.91 and 117.98 mg/kg DM (Table 3). Tepe [*26*] found that HMF values in melon dried with different pre-treatments and drying methods ranged from 0.1 to 8.94 mg/kg DM. These reported values are much lower than our values. It may be due to the differences in the melon varieties, drying methods, pre-treatments, and applied parameters. In addition, the high sugar content of the melon and the effect of thin slices may have contributed to the increase in HMF levels. The HMF content of CA, CA+ET, CA+BL, and CA+FT samples was low. Especially the pretreatments involving ultrasound (CA+US, CA+ET+US, CA+ET+US+BL, CA+ET+US+FT) led to the higher HMF content. The effect of ultrasound on HMF increase was higher than that of ethanol, blanching, and freezing. This may be due to tissue damage and local heat increase as a result of cavitation during ultrasound application. The highest HMF content was also found in the CA+US sample ($p<0.05$). Although the CA+US pretreatment has a similar cavitation effect as the other pretreatments containing ultrasound, the drying time of the samples produced by CA+US pretreatment is higher ($p<0.05$). The differences among the pretreatments in terms of HMF values were statistically significant ($p<0.05$).

Bioactive compounds of melon chips

Total phenolic contents and antioxidant activities of melon chips are given in Table 4. Total phenolic content, DPPH, and ABTS assay of fresh melon were found 2784.78 mg GAE/kg DM, 17.32, and 22.15 mmol TE/g DM, respectively. These values of melon chips were 1701.90–2565.34 mg GAE/kg DM, 4.86–7.47, and 5.19–14.88 mmol TE/g DM, respectively. The total phenolic content and antioxidant activity of melon chips were found to be lower than those of fresh samples ($p<0.05$). It was shown that pretreatments and drying caused loss of antioxidant compounds. A study by Kaveh *et al.* [*28*] recorded similar results and reported the loss of TPC and AA in dried rose petals pretreated with ultrasound, ethanol, and their combinations. The highest total phenolic content and antioxidant activity values were determined in CA and CA+ET pretreatment. The total phenolic content and antioxidant activity values of samples prepared by multiple pretreatments were lower when compared to the CA sample as a control. The decreases observed in the CA+BL and CA+FT samples were found to be similar. Blanching and freeze-thawing pretreatments may cause physical damage to cell structures and increase the porosity and surface area of the samples, they may accelerate the release of bioactive compounds during drying, followed by their degradation or oxidation [*37*]. In particular, losses were high in multiple pretreatments including ultrasound. The highest loss of phenolic compounds and the lowest antioxidant activity values were observed in the CA+ET+US+FT sample. Generally, antioxidant activity values and total phenolic content of samples changed in the same way. The differences between the samples for total phenolic content, DPPH, and ABTS values were statistically significant ($p<0.05$). da Cunha *et al*. [*11*] reported that the total phenolic content of fresh cantaloupe melon was 3.66 mg GAE/g DM and the drying process reduced the total phenolic content. Tepe [*26*] stated that while the DPPH value of fresh melon is 4.44 mmol TE/g DM, DPPH values of melon dried after different pre-treatments ranged from 1.33 to 2.11 mmol TE/g DM. Nicoli *et al*. [*38*] reported that during the processing of foods, phenolic compounds undergo chemical, enzymatic, or thermal degradation, and therefore, antioxidant activity decreases.

Sensory attributes of melon chips

The results from the sensory evaluation are given in Table 5. Significant differences were found among the samples in evaluated characteristics except odor and taste ($p<0.05$). The most liked samples in terms of appearance were the CA+US, CA+ET+US, and CA+ET+US+BL samples. CA+ET+US+BL sample had the highest score in terms of color. While the CAE sample had the best results in terms of color values (*L**, *a**, and *b**), the lowest color score was given to CA+ET sample in sensory evaluation. This may be due to the habit of people in Türkiye to consume darker colored sun-dried products. CA+ET+US+FT and CA+BL samples were close to each other and had the highest scores for hardness and stickiness, while CA+BL and CA+ET samples had the highest scores for sourness. The CA+BL sample had the highest scores in several sensory parameters, especially in general acceptance. This may be due to the blanching process in citric acid/blanching combination, as it removes raw tastes and odors, and its positive effect on texture with high hardness and stickiness scores. However, it has also been determined that when compared to CA, multiple combinations did not cause dramatic declines in sensory scores. Multiple pretreatment applications due to the combination of several positive effects generally had a higher sensory score than CA.

PCA analysis

The PCA results were presented in the form of a biplot (Fig. 2). The first three principal components were found to account for 38.01, 23.29, and 13.64 % of the variation, respectively. The cumulative proportion of variation approached 74.94 % of the total variation. The traits contributing to this high variation in the first PCA component (PC 1) were moisture, RR, sucrose, hardness, taste, stickiness, and general acceptance. Traits contributing to the second PCA component (PC 2) were *L**, *a**, fructose, HMF, TPC, DPPH, ABTS, appearance, and color. The third PCA component (PCA 3) was related to *b**, shrinkage, glucose, total sugar, odor, and sourness. While the effect of RR on variation was the lowest, shrinkage had the highest effect on variation. The effects of other traits on variation were similar. While the effects of *a**, HMF, color, and appearance in PCA 2 were negative, *L**, TPC, DPPH, and ABTS were positive. As expected, a strong negative correlation was found between *L** and *a** values. It was a result of the enzymatic or non-enzymatic browning reactions that occur during pre-treatment and drying. Although there was a high positive correlation between TPC and antioxidant activity values, no correlation among *a**, HMF, and antioxidant activity values. The results suggested that phenolic were the main contributors of antioxidant activity of the melon chips and browning pigments formed by Maillard reactions during pretreatment and drying had no or limited effect on antioxidant activity. The significant correlations were also identified between taste and hardness, taste and stickiness, general acceptance and stickiness, taste and general acceptance.

They showed that the physical state of melon chips in the mouth had a more significant effect on taste and general acceptance than other sensory characteristics. Color is the most influential parameter on appearance. Therefore, the highest correlation was found between color and appearance. Samples produced using ultrasound had high HMF content, *a** values, and dark colors. Since people in Türkiye have a habit of consuming sun-dried dark-colored products, the panelists gave high scores to samples with high HMF and *a** values in terms of color and appearance. As a result, the *a**, *b**, HMF, color, and appearance parameters contributed most to the distribution models of the ultrasonic effect (below and right of the PC1 axis) (Fig. 2). CA was clearly positioned in the same quartile (below and right of the PC1 axis) with sugars, TPC, and antioxidant activity. CA was already characterized by better preservation of sugars, phenolic content, and AA capacity. A clear distinction was observed between CA+BL and CA, CA+BL and applications contain ultrasound. While the CA+BL was located far away from sugar, phenolic, and AA parameters, positioned in the same place as sensory parameters, except for color and appearance. When compared to other samples, the CA+BL sample was characterized by high loss for sugars and moderate loss for TPC and AA due to the effect of heat and extraction during blanching. However, it had the highest liking scores in sensory evaluation parameters. While only CA sample as the control group was located in the positive region, the CA+ET, CA+FT, and CA+BL were clustered in the region opposite CA. All applications involving ultrasound and multiple combinations were located in the negative ordinate region. In particular, the CA+ET+US+FT sample stood out distinctly from the others.

CONCLUSIONS

Various pretreatments are used to eliminate or limit many of the negative effects of the drying process on the product. As an innovative drying technique, vacuum-assisted two-way infrared drying can have some disadvantages, such as high heat transfers and fast drying. This study investigated the effect of different pretreatment combinations on the quality characteristics of melon chips produced by a vacuum-assisted two-way infrared dryer. Among the different pretreatments (freezing, blanching, ultrasound, and ethanol), freezing was the pretreatment that shortened the drying time the most. In particular, the use of freezing with other pretreatment combinations (CA+ET+US+FT) resulted in the shortest drying time and the lowest specific energy consumption. This method has positively improved the rehydration and shrinkage properties of melon chips. However, it has significantly reduced the phenolic content and antioxidant activities of the samples. The presence of ultrasound in the pretreatment application led to substantial increases in HMF content. The combination of citric acid and blanching (CA+BL) was the most suitable pretreatment combination for the production of melon chips by two-way infrared drying under vacuum with low pretreatment time and HMF content, moderate phenolic content, and antioxidant activity, and the highest general acceptance score despite the high specific energy requirement and infrared drying time. However, the absence of drying kinetics is one of the study's limitations. The results showed that many of the disadvantages (such as surface crusting and browning) arising from the rapid drying effect of vacuum-assisted two-way infrared dryers can be eliminated by using various combinations of pretreatments. This will enable the production of high-quality fruit chips with shorter processing times and lower energy consumption.

FUNDING

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ETHICAL APPROVAL

A sensory evaluation of melon chips was conducted at Van Yüzüncü Yıl University (Van, Türkiye) with adult volunteers. Participation was voluntary, oral informed consent was obtained before inclusion, and confidentiality was ensured through anonymous data collection. No invasive procedures were involved, and all steps followed internationally accepted ethical principles for human sensory evaluation. According to institutional and national guidelines, formal ethics committee approval was not required for this type of harmless sensory study.

CONFLICT OF INTEREST

The authors declare that they have no competing interest, or similar.

AUTHORS' CONTRIBUTION

GÇ was responsible for conceptualization, formal analysis, investigation, writing - original draft, SU was responsible for investigation, methodology, writing - original draft, writing - review and editing, TY was responsible for formal analysis and methodology, EB was responsible for conceptualization, investigation, methodology, funding acquisition, project administration, writing - review and editing. All authors read and approved the final version of the manuscript.

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Table 1. Moisture content, pretreatment time, drying time and processing time of melon chips (*N*=5)

Sample	*w*(moisture)/%	*t*/min		
		Total pretreatment	Infrared drying	Total processing
Fresh	89.44±1.72	-	-	-
CA	(7.43±0.01)[cd]	7	155	162
CA+ET	(8.24±0.07)[ab]	7	135	142
CA+US	(6.62±0.17)[e]	20	135	155
CA+ET+US	(6.93±0.51)[ab]	20	92.5	112.5
CA+BL	(8.95±0.50)[a]	7	135	142
CA+ET+US+BL	(7.34±0.34)[cde]	20	90	110
CA+FT	(8.64±0.25)[de]	967	105	1072
CA+ET+US+FT	(8.05±0.27)[bc]	980	72.5	1052.5

Data are expressed as mean value±standard deviation. Lower case letters indicate the difference between samples in the same column ($p<0.05$)

Table 2. Color values, rehydration ratio, and shrinkage ratio of melon chips (n=5)

Sample	*L**	*a**	*b**	Rehydration ratio/%	Shrinkage ratio/%
Fresh	59.20±5.92	0.31±0.71	9.65±3.00		
CA	(65.76±4.84)[bc]	(11.25±0.94)[cd]	(31.65±2.53)[bc]	(3.57±0.16)[e]	(87.6±1.34)[cd]
CA+ET	(74.21±5.39)[a]	(9.7±0.49)[d]	(34.05±2.99)[b]	(5.48±0.11)[b]	(94.3±2.47)[a]
CA+US	(56.71±3.16)[d]	(16.14±1.17)[a]	(39.67±3.11)[a]	(4.24±0.17)[d]	(90.0±0.0)[bc]
CA+ET+US	(68.69±3.11)[ab]	(11.32±0.63)[cd]	(33.12±0.95)[bc]	(3.69±0.16)[e]	(92.0±0.0)[ab]
CA+BL	(60.35±1.47)[cd]	(11.74±0.94)[bc]	(30.83±1.20)[bcd]	(3.61±0.08)[e]	(91.6±0.62)[b]
CA+ET+US+BL	(60.14±3.69)[cd]	(13.32±1.16)[b]	(34.45±0.98)[b]	(5.00±0.05)[c]	(90.0±0.0)[bc]
CA+FT	(63.35±6.67)[bc]	(12.21±0.76)[bc]	(29.43±0.93)[cd]	(5.36±0.04)[bc]	(88.2±0.23)[cd]
CA+ET+US+FT	(67.17±1.12)[abc]	(9.82±1.33)[d]	(27.76±1.61)[d]	(6.07±0.40)[a]	(85.7±0.0)[d]

Data are expressed as mean value±standard deviation. Lower case letters indicate the difference between samples in the same column ($p<0.05$)

Table 3. HMF and sugar content of melon chips (*N*=5)

Sample	*w*(HMF)/(mg/kg)	*w*(sugar)/(g/100 g)			
		Fructose	Glucose	Sucrose	Total sugar
Fresh		20.64±1.41	22.44±3.16	33.35±3.86	76.43±5.24
CA	$(41.91±1.10)^{f}$	$(20.11±0.05)^{a}$	$(20.87±0.57)^{a}$	$(24.36±0.08)^{bc}$	$(63.34±0.89)^{a}$
CA+ET	$(60.06±1.61)^{d}$	$(16.53±1.55)^{a}$	$(17.39±2.57)^{a}$	$(25.15±2.84)^{bc}$	$(59.07±4.84)^{ab}$
CA+US	$(117.98±2.85)^{a}$	$(16.08±1.31)^{a}$	$(17.12±0.61)^{a}$	$(23.34±1.36)^{bc}$	$(56.54±0.56)^{b}$
CA+ET+US	$(74.92±0.77)^{c}$	$(15.55±0.90)^{a}$	$(15.22±1.82)^{a}$	$(27.28±0.70)^{a}$	$(58.05±0.81)^{ab}$
CA+BL	$(52.80±0.13)^{e}$	$(13.63±0.03)^{ab}$	$(15.13±2.20)^{a}$	$(17.92±0.41)^{c}$	$(46.68±2.58)^{b}$
CA+ET+US+BL	$(82.52±0.73)^{b}$	$(15.52±0.05)^{a}$	$(13.94±0.53)^{a}$	$(28.52±0.20)^{b}$	$(58.28±0.69)^{ab}$
CA+FT	$(48.80±0.31)^{e}$	$(18.8±0.95)^{a}$	$(19.79±0.65)^{a}$	$(25.12±2.58)^{bc}$	$(63.71±3.02)^{a}$
CA+ET+US+FT	$(80.91±0.74)^{b}$	$(9.5±1.11)^{b}$	$(17.31±1.06)^{a}$	$(16.03±1.24)^{c}$	$(42.84±0.93)^{b}$

Data are expressed as mean value±standard deviation. Lower case letters indicate the difference between samples in the same column ($p<0.05$). HMF=5-hydroxymethylfurfural

Table 4. Total phenolic content, DPPH, and ABTS values of melon chips (*N*=5)

Sample	*w*(total phenolic as GAE)/(mg/kg)	*b*(TE)/(mmol/g)	
		DPPH	ABTS
Fresh	2784.78±20.46	17.32±0.43	22.15±7.26
CA	$(2565.34±39.56)^{a}$	$(7.47±0.42)^{a}$	$(13.40±1.36)^{ab}$
CA+ET	$(2491.56±54.6)^{a}$	$(7.10±0.40)^{a}$	$(14.88±2.06)^{a}$
CA+US	$(2034.64±101.95)^{bc}$	$(7.04±0.37)^{a}$	$(11.59±2.90)^{abc}$
CA+ET+US	$(1992.07±142.27)^{b}$	$(6.90±0.86)^{a}$	$(8.71±2.54)^{c}$
CA+BL	$(2096.89±354.01)^{bc}$	$(7.04±0.24)^{a}$	$(10.40±0.30)^{bc}$
CA+ET+US+BL	$(1961.90±102.65)^{bc}$	$(6.15±1.11)^{ab}$	$(11.83±0.06)^{abc}$
CA+FT	$(2133.74±33.51)^{b}$	$(6.36±1.55)^{a}$	$(10.49±1.19)^{bc}$
CA+ET+US+FT	$(1701.90±60.93)^{c}$	$(4.86±0.51)^{b}$	$(5.19±1.05)^{d}$

Data are expressed as mean value±standard deviation. Lower case letters indicate the difference between samples in the same column ($p<0.05$). GAE=gallic acid equivalents, TE=Trolox equivalents

Table 5. Sensory characteristics of melon chips

Sample	Appearance	Color	Odor	Hardness	Taste	Stickiness	Sourness	General acceptance
CA	$(7.08\pm1.49)^{ab}$	$(7.00\pm1.73)^{ab}$	$(6.31\pm2.05)^{a}$	$(4.62\pm1.66)^{c}$	$(5.85\pm2.07)^{a}$	$(6.00\pm2.27)^{ab}$	$(5.23\pm2.20)^{b}$	$(6.31\pm2.21)^{ab}$
CA+ET	$(5.54\pm2.63)^{b}$	$(4.92\pm2.53)^{c}$	$(6.46\pm1.89)^{a}$	$(7.00\pm1.58)^{a}$	$(6.85\pm2.41)^{a}$	$(6.69\pm2.09)^{ab}$	$(7.31\pm1.31)^{a}$	$(5.77\pm2.20)^{ab}$
CA+US	$(7.42\pm1.43)^{a}$	$(7.17\pm1.11)^{ab}$	$(6.08\pm1.51)^{a}$	$(5.53\pm2.06)^{bc}$	$(5.83\pm2.12)^{a}$	$(5.75\pm2.13)^{b}$	$(6.08\pm0.80)^{ab}$	$(5.58\pm1.88)^{b}$
CA+ET+US	$(7.38\pm1.44)^{a}$	$(7.08\pm1.32)^{ab}$	$(6.77\pm1.48)^{a}$	$(6.31\pm1.97)^{ab}$	$(6.92\pm1.99)^{a}$	$(7.15\pm1.77)^{ab}$	$(6.15\pm1.90)^{ab}$	$(7.00\pm1.68)^{ab}$
CA+BL	$(6.23\pm2.20)^{ab}$	$(6.00\pm2.04)^{bc}$	$(6.38\pm1.89)^{a}$	$(7.62\pm1.26)^{a}$	$(7.23\pm1.42)^{a}$	$(7.62\pm1.12)^{a}$	$(6.85\pm1.99)^{a}$	$(7.38\pm1.12)^{a}$
CA+ET+US+BL	$(7.46\pm1.45)^{a}$	$(7.62\pm1.26)^{a}$	$(7.08\pm1.49)^{a}$	$(6.38\pm2.21)^{ab}$	$(6.54\pm1.50)^{a}$	$(6.08\pm2.59)^{ab}$	$(6.08\pm2.01)^{ab}$	$(6.23\pm1.92)^{ab}$
CA+FT	$(6.38\pm1.55)^{ab}$	$(6.08\pm1.70)^{abc}$	$(7.15\pm1.46)^{a}$	$(6.85\pm1.99)^{ab}$	$(6.62\pm2.29)^{a}$	$(6.62\pm2.21)^{ab}$	$(6.54\pm1.94)^{ab}$	$(6.31\pm2.01)^{ab}$
CA+ET+US+FT	$(6.67\pm2.10)^{ab}$	$(6.58\pm2.02)^{ab}$	$(6.58\pm1.68)^{a}$	$(7.67\pm1.50)^{a}$	$(7.08\pm1.7)^{a}$	$(7.75\pm1.48)^{a}$	$(6.50\pm1.57)^{ab}$	$(7.00\pm1.41)^{ab}$

Data are expressed as mean value±standard deviation. Lower case letters indicate the difference between samples in the same column ($p<0.05$)

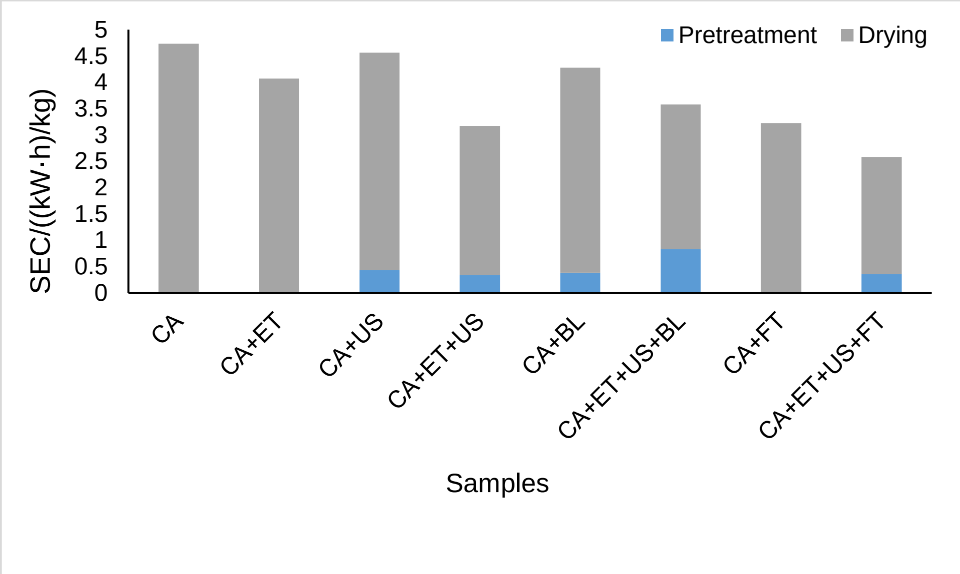

Fig. 1. Specific energy consumption (SEC) in melon chips production

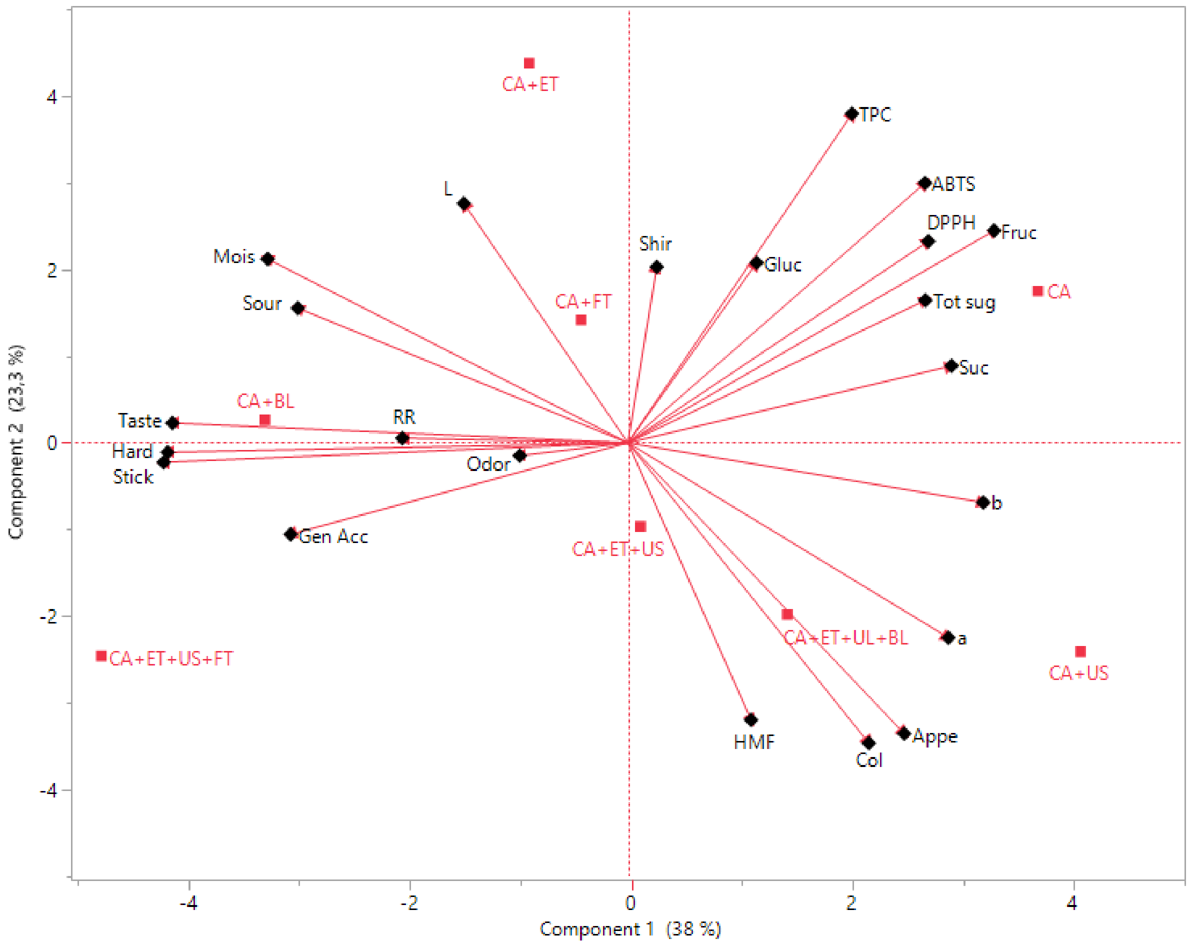

Fig. 2. Biplot PCA results. CA=citric acid pretreatment, CA+ET=citric acid/ethanol pretreatment, CA+US=citric acid/ ultrasound pretreatment, CA+ET+US=citric acid/ethanol/ ultrasound pretreatment, CA+BL=citric acid/ blanching pretreatment, CA+ET+US+BL=citric acid/ethanol/ultrasound/blanching pretreatment, CA+FT=citric acid/freezing pretreatment, CA+ET+US+FT=citric acid/ethanol/ultrasound/freezing pretreatment, L=lightness, a=redness, b=yellowness, Mois=moisture, RR=rehydration rate, Shir=shrinkage ratio, TPC=total phenolic content, ABTS=ABTS scavenging activity, DPPH=DPPH scavenging activity, Gluc=glucose, Fruc=fructose, Suc=sucrose, Tot sug=total sugar, HMF=5-hydroxymethylfurfural, Col=Color, Appe=appearance, Sour=sourness, Hard=hardness, Stick=stickiness, Gen Acc=general acceptance